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Numerical analysis of force-feedback control in a circular tank

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ABSTRACT

The advent of circular wave tanks, with wave-making segments all around the perimeter, brings potential advantages over standard, rectangular wave tanks where the wave-maker is confined to one or two adjacent sides of the tank. It is now possible to reproduce seas with full 360° directionality, enhancing the range of possible test scenarios. However, this additional capability also presents technical challenges: waves generated on "one side" of the tank must be absorbed on the opposite side, together with any waves reflected or radiated by the model under test, to prevent contamination of the wave field. This paper reviews the theory of wave generation and absorption in a circular tank, before proceeding to identify an appropriate control scheme for the University of Edinburgh's "FloWave" combined wave/current basin. Numerical simulations, based on linear multi-chromatic waves, are carried out using WAMIT to assess the suitability of wave-maker control schemes suggested in literature. For the first time a round tank's ability to reproduce sea spectra is assessed numerically. The simulations suggest that the generation of "peaked" spectra is possible to an accurate degree, with an overall standard deviation error of less than 2% over a designated "test zone". However, there are difficulties in producing "wide" spectra, as effective dynamic wave absorption cannot be ensured over the whole frequency range. This may have important repercussions, not just for the usage of FloWave, but also in terms of the design of future round basins.

1. Introduction

There are numerous wave tank facilities in the world capable of generating multi-directional waves through the computer-controlled, serpentine motion of a segmented wave-maker along the perimeter of the tank. Typically these tanks are of rectangular shape, with wave-making panels on one or two adjacent sides of the tank, and absorbing beaches on one or more of the remaining sides. Indeed much of the theory developed for the control of segmented wave-makers assumes a rectangular tank, and/or a linear arrangement of wave-making panels. However, the requirement for a wider range of wave directions, as well as more compact tank size, has led to the development of circular tanks. In these tanks, the wave-maker extends around the entire rim, and the wave-making segments are able to generate as well as absorb waves, allowing the simulation of seas with any combination of wave directions. Examples of circular tanks described in literature include the Deep Sea Basin at the National Maritime Research Institute in Tokyo [1], the AMOEBA tank in Osaka [2], and FloWave TT [3], a combined current and wave test basin recently constructed at Edinburgh. Table 1 compares the main features of these tanks.

This paper considers wave-making in the FloWave test facility. The basin, designed for model testing at approximately 1:20 scale, comprises an array of 168 dry back, flap-type wave boards. Force-feedback control is used, which is considered to have advantages over position-control, in that the spurious harmonic content in the wave field tends to be reduced [4]. Moreover, force-feedback control lends itself better to wave absorption, which can be implemented through the simple addition of a velocity feedback loop in the control system [5]. Currents in FloWave are generated using a set of 28 impellers that pump water into and out of test area via turning vanes, the flow being recirculated through a plenum chamber, as shown in Fig. 1. The turning vane layout is designed to leave an undisturbed region directly in front of the wave boards, so as currents do not to interfere with the wave generation or absorption process.

Here it is assumed that solely waves are generated in the tank, and a thorough review is carried out of linear wave generation and absorption, as applicable to the control of a round tank. Numerical computations are then carried out to assess a number of possible control schemes for the tank, in terms of the resulting steady state behaviour.

In its typical operating scenario, FloWave is expected to reproduce realistic sea spectra. Ideally, the generated sea should extend

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Table 1
Characteristics of circular tanks.

Tank	FloWave TT [3]	NMRI [1]	AMOEBA [2]
Diameter	25 m	14 m	1.6 m
Actuator	168 force-feedback, dry back paddles	128 position-feedback, wet back paddles	50 force-feedback plungers
Depth	2 m	5 m	0.25 m
Maximum wave height	0.7 m (planned)	0.5 m	0.02 m
Wave period range	1–3 s (planned)	0.5–4 s	0.33–0.625 s

over a large proportion of the tank, allowing for the testing of large scale models or device arrays. The present paper makes the following important contributions in assessing the prospective capabilities of the tank:

- The ability of the tank to reproduce sea spectra in a spatially uniform manner is investigated.
- The impact of a single malfunctioning paddle on the generated sea spectra is explored.
- The response of a floating body in the middle of the tank is considered, and compared with the expected body motion given the prescribed sea spectrum.

The present paper contains the first numerical study of a round tank generating multi-chromatic waves, and whilst the focus is on FloWave, the results and methodology are relevant for round tanks in general.

To simulate the tank, the approach of Newman [6], based on the commercial boundary element method (BEM) solver WAMIT, is applied. The approach has been validated experimentally for a 96° arc of paddles in the Edinburgh Curved Tank by Gyongy et al. [7]. A key advantage of using a linear diffraction solver, is that it is simple to apply to a circular (or indeed any) tank geometry. Moreover, it lends itself well to modelling force-control, as the hydrodynamic forces on the paddles, and the associated paddle motions, are easily established. Given the linearity of the approach, the waves from each paddle may be computed separately, and then superposition applied to obtain the overall wave field.

Other methods for analysing linear wave-making in a tank include analytical approaches modelling the individual paddles as point sources or finite width sources [8,9], or the collection of paddle faces as one continuous surface. Whilst most techniques assume position-controlled wave-makers (with given motions imposed), Spinneken et al. [4] consider the force-control of a rectangular tank with absorbing wave-makers, deriving a theoretical first-order transfer function backed up by experimental observations. A drawback of analytical approaches is that reflections can be difficult to model. In a simpler scenario, when the line of wave-makers faces a bank of absorbing beaches (as in a typical rectangular tank), the reflecting side walls may be readily accounted for [10]. However, analysing reflections (and re-reflections) off a round boundary, or indeed the effect of an object in the tank on the wave field, would be too complex. An alternative, numerical option is to use a spectral method [11].

It is important to note that the linear waves analysed here only represent a subset of the test scenarios that a wave basin is expected to provide. Indeed, one of the rationales behind physical testing is that it allows non-linear wave/structure interactions to be examined, which are often difficult to analyse numerically in a reliable way. Hence there is a requirement to reproduce non-linear, in particular high steepness waves, in an accurate wave. This paper, in staying in the domain of linear waves, is intended to constitute a first step in identifying a viable control scheme for FloWave, and a discussion is included on the implications of generating non-linear waves.

The paper is organised as follows. Section 2 reviews the theory for controlling a circular wave tank, with absorbing, force-feedback paddles. A basic physical model for wave boards is first outlined, followed by the control loop around wave boards. Potential control strategies for the whole tank are then discussed. In Section 3, the methodology of simulating force-control and dynamic absorption in a circular tank using WAMIT is described. Section 4 presents the results of simulations, both for the control of the "empty" FloWave basin and for the case of a floating object in the tank, which results in radiated and diffracted waves. Section 5 discusses non-linear waves. Conclusions are given in Section 6.

2. Modelling a circular tank

2.1. Paddle dynamics

As outlined in Spinneken et al. [12], a flap-type wave board, depicted in Fig. 2, may be considered as an inverted pendulum with mass m and inertia r. The tangential weight component is

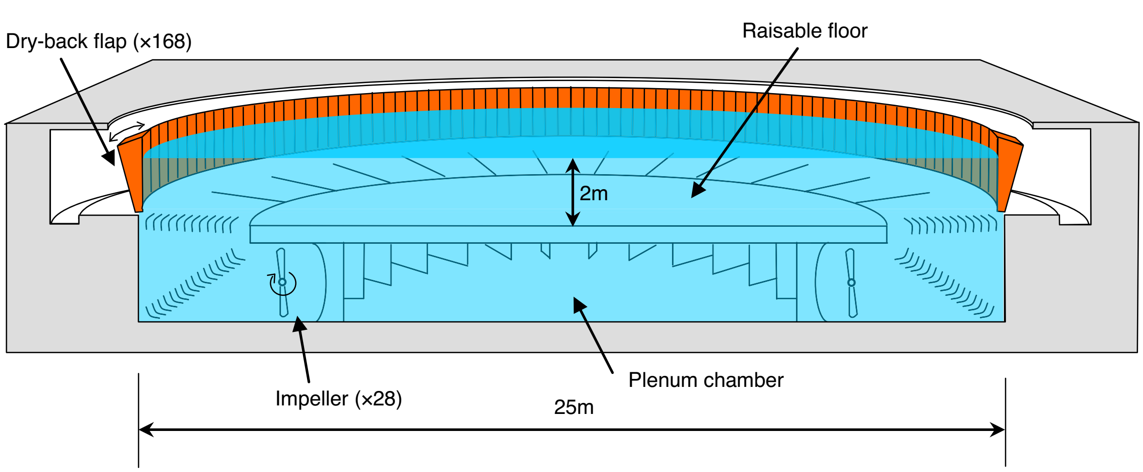

Fig. 1. Cross-sectional diagram of FloWave TT.